PRESSURE VELOCITY AND LEADSCREW ASSEMBLIES
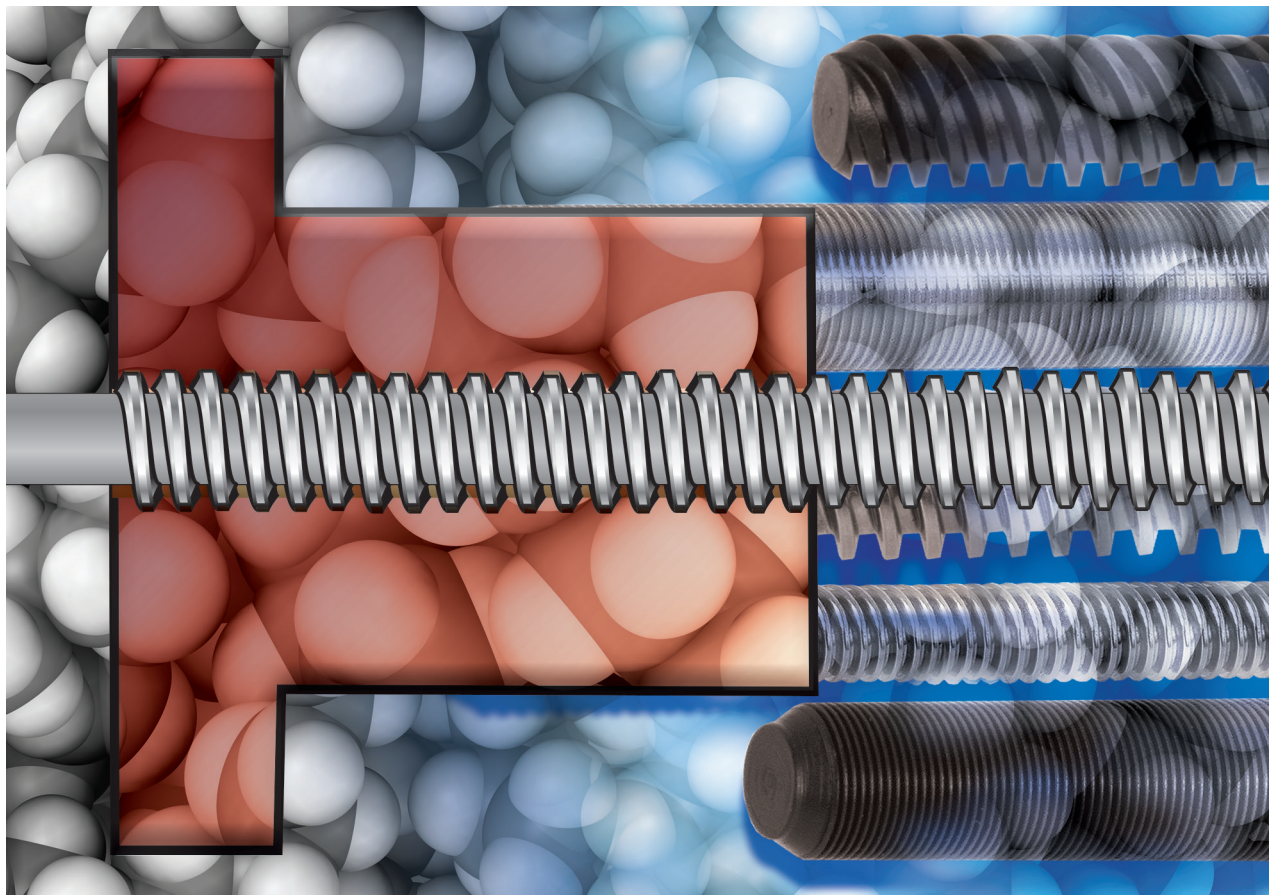

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Pressure velocity (PV) is a fundamental property of all plastics, and is specific to the composition of the plastic. PV for a lead screw application is a calculated value based on load and surface speed of the interface between the leadscrew and nut. Limiting PV is a term used by manufacturers to characterize the amount of heat generation a plastic can withstand before compromising physical properties such as the geometry of the part. Every plastic has a maximum PV value defined by the manufacturer, which should only be exceeded under specific circumstances. Manufacturer's limiting PV values should be considered to make decisions on proper loading, speed, and duty cycle of the assembly. The following will explain PV and why it is important, basic example for calculating PV in a leadscrew application, and what happens when the PV of a material is exceeded.
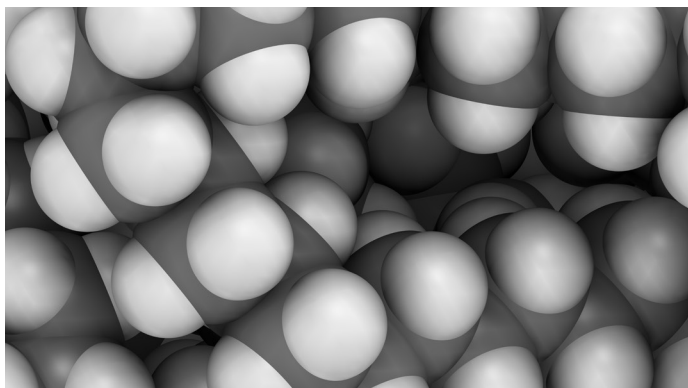
Composition of polyethylene molecule affects pressure velocity. White = Hydrogen, Gray = Carbon

Considering Materials of Composition

The load in a leadscrew application can be defined as total axial thrust, which is acceleration of the load and the drag on the system . To help understand the relationship of load and speed, PV can be viewed as a curve on a graph. One axis is plotted as linear velocity of a plastic while the other is pressure the plastic imposes on a surface. This means that if a specific application is operating at or near the limiting PV of the material, and the load is increased, the speed should be decreased to stay within the safe operating conditions.

The PV of a plastic is based on the material composition. This PV rating is given by suppliers when they release the material specification. The actual PV of the material may not match the specification, due to the manufacturers adding a safety factor. This added safety factor can cause confusion when comparing similar products from various polymer manufacturers. PV ratings can also be adjusted by altering the chemical composition of a plastic. The physical characteristic of being able to withstand heat generation is desirable for raising the limiting PV of an engineered polymer. While this typically makes polymer nuts stronger, it generally raises the coefficient of friction which lowers the efficiency of the leadscrew assembly. This is why it is important to properly select a material for a specific application. Using a polymer with a higher PV value does not necessarily mean the plastic nut will last longer or perform better for that application. Generally, it is better to use a plastic with lower coefficient of friction, as long as that material will support the load and speed for a given application.

Evaluating an Application

The capabilities of engineered polymers in a leadscrew application are dependent on the application specifications. Let's say we have an 18.5 lb. load, which we want to move at 2 in/s. To calculate PV of this system we still need the diameter and

lead of the lead screw. If we select a 0.375 (3/8) inch diameter by 0.1 inch lead, we can now calculate the PV of the application. Helical Travel tells us the linear distance the nut travels during each revolution,

Equation 1.

$$X_{helix} = \sqrt{lead^2 + \pi P_D^2}, \quad \text{Substituting}$$

$$= \sqrt{0.1^2 + \left[\pi \left(\frac{0.375 + 0.266}{2} \right) \right]^2}$$

$$= 1.0119 \ in/rev$$

Where:

Helical Travel is X_{helix}

Pitch diameter is P_D and is equal to $\frac{OD + RD}{2}$

OD is the Outer Diameter (Reference material)

RD is the Root Diameter (Reference material)

Knowing the helical travel now allows for the surface area of thread engagement to be found. Area is equal to the Helical Travel times the width of the thread. This area can be thought of and a rectangular area wrapped around the leadscrew,

Equation 2.

$$SA_{thread} = X_{helix} * \frac{OD - RD}{2}, \quad \text{Substituting}$$

$$= 1.0119 * \frac{0.375 - 0.266}{2}$$

$$= 0.05515 \ in^2$$

Where: SA_{thread} is the surface area of one revolution of one thread

In order to convert our linear velocity to proper units, revolutions per second can be found by taking the linear velocity and dividing by the chosen lead.

Equation 3.

$$RPS = \frac{V_{linear}}{lead}, \quad \text{Substituting}$$

$$= \frac{2}{0.1}$$

$$= 20 \ RPS$$

Where: V_{linear} is linear velocity

In order to convert to revolutions per minute (RPM), multiply by 60 seconds

Equation 4.

$$RPM = RPM * 60$$

$$= 20 * 60$$

$$= 1200 \ RPM's$$

The travel speed of the application is referred to in feet per minute, which can be found by multiplying the RPM's of the system by the helical travel and dividing that by 12 to get from inches to feet,

Equation 5.

$$V_{travel} = \frac{RPM * X_{helix}}{12}, \quad \text{Substituting}$$

$$= \frac{1200 * 1.0119}{12}$$

$$= 101.19 \ fpm$$

Where: V_{travel} is the travel speed in feet per minute

To calculate the PV of the application the travel velocity needs to be multiplied by the load on the system and then divided by the Total Area of Engagement. For the purpose of this paper, and for simplicity, the load will take into account all forces during movement.

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Equation 6.

$$PV = \frac{V_{linear} * LOAD}{SF * A_{ENGAGE}} \,, \quad \text{Substituting}$$

$$= \frac{101.19 * 18.5}{3 * 0.05515}$$

$$= 11.314 \text{ psi} * \text{fpm}$$

Where: PV is pressure velocity

A_{ENGAGE} is the total area of thread engagement

The Total Area of Engagement is equal to three times the Surface Area of one thread. As was discussed earlier in this paper, a factor of safety can be applied at different steps during the PV calculation. It can be applied to the material property, or the area used to calculate the pressure. This is where opinions may differ of which way is best to introduce a factor of safety to the PV calculation. Some may use the whole thread engagement area and apply a factor of safety to the material itself, while others will reduce the area of thread engagement as the factor of safety. Individual manufacturers have years of experience applying one method or another, and are a valuable resource for customers to assist in selecting the proper material for a specific application.

For the application outlined above, after substituting the numbers, the PV is calculated to be 11,314 psi * fpm. This is very close to the specified PV limit of many standard lubricated acetyl polymers. To verify that this will not be a problem the duty cycle and ambient conditions of the application will be important. If the duty cycle of the assembly is known, and approaches 100% there are several factors to change which will lower the PV of the assembly which includes physical parameters that will effect product performance. Some of these changes are outlined in the previously published article "Leadscrews 101", which outlines the details of a leadscrew assembly, and which parameters can be adjusted to compensate for high PV values.

A good standard for testing PV of a material is to take a puck of known diameter, and run it along a static surface (see figure 1). The cut-away figure below shows pucks that are loaded with a spring force to allow for all variables in the PV equation to be known and to verify the manufacturer's data for a specific material. This can be directly related to the leadscrew equations above if we replace the surface area of the puck with the surface area of the thread (SA_{thread}). This can be used to accurately make assumptions for leadscrew applications because the velocity, surface area, travel distance and load of the pucks are all known.

Figure 1: Rotational wear tester cut-away

Rotating test device

Spring force

Tested plastic material "puck"

Stationary surface area
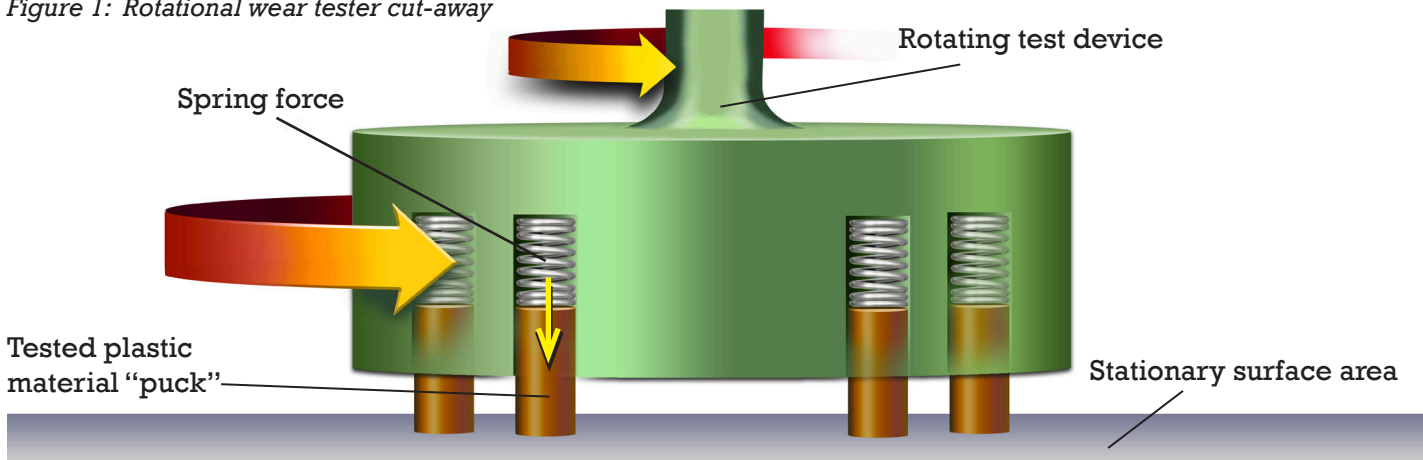
Applications

It is difficult to account for off axis loading during the design of a specific application, and because of this it is highly advised that all applications be tested for proper function over time. For a complete characterization of the assembly lifecycle testing should be performed. Accelerated lifecycle testing is discouraged as it will typically change the PV of the application due to increased velocity or load conditions. Changing either of these parameters will increase the PV of the assembly and could lead to PV failure. One way to reduce full lifecycle testing is to run the application at normal operating conditions for some fraction of the total lifecycle and measure the wear. Using this wear data the total life expectancy of the assembly can be extrapolated out to estimate the effective life of the lead screw assembly.

Only in extreme cases will PV failure happen catastrophically. Typically when an application exceeds PV of the plastic nut, the clearances in the threadform are reduced, due to the flowing of the plastic. When the clearances of the threadform are reduced, the drag on the nut assembly is increased, which increases the PV in the assembly. This cycle will create a run-away increase in PV which will eventually seize the nut on the leadscrew. If the loading on the leadscrew is not perfectly axial, then the PV of the assembly may not be properly calculated. Off axis loading will cause a moment on the nut and will greatly decrease the area of contact at the bearing surface. As demonstrated in the equations above this decreased area of contact at the bearing surface will increase the PV of the application, which could lead to PV failure.

CONCLUSION

Engineering polymers have improved greatly over the past few decades. Manufacturers now have the ability to mold in reinforcement materials which now allow loading of polymers to far exceed the capabilities of plastic nuts in the past. Even though the strength of these nuts is very high, the efficiency of the leadscrew to nut interface is superior to that of a metal on metal interface. Other engineered polymers have been designed to have extremely high sliding efficiencies by molding in lubrication materials like PTFE to other polymers, which allow some manufactures to achieve nearly 90% efficiencies of the leadscrew assemblies. Polymer leadscrew nuts will generally outlast their metal counter parts in life as well. All of these factors listed have changed the way that PV is calculated by engineers, and allow leadscrew assemblies to enter into applications, where only a few decades ago a leadscrew and nut would never be successful.

This technical presentation was prepared by the engineering team at Haydon Kerk Motion Solutions, a leader in linear motion technologies. Complex custom and ready-to-ship standard lead screw assemblies are made at U.S. facilities with a full range of on-site capabilities including designing, engineering and manufacturing.

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